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RESEARCH AND DEVELOPMENT
REPORT 295
APRIL 1966

Interim Report

VISIBILITY OF NAVIGATIONAL LIGHTS IN A SUBMARINE ARRAY

Subproject SF 013 12 06, Task 4801

HERBERT LARRIMORE

ABSTRACT

The U. S. Navy Mine Defense Laboratory conducted a series of tests on a simulated nuclear submarine running light array at sea under normal nighttime operating conditions. The tests were made to determine the maximum range at which the light array could be recognized. Observers were selected from military personnel who normally stand duty watch as lookouts. Tests indicated that with an atmospheric transmission rate of 70 percent per nautical mile the maximum range of visibility for the lights in the array was: white masthead light, 9.3 miles; green starboard sidelight, 2.1 miles; and red port sidelight, 2.3 miles.

ADMINISTRATIVE INFORMATION

Subproject SF 013 12 08, Task 4601 was established by Bureau of Ships letter F013-12-08 Serial 660W-2521 of 7 June 1963, for development, improvement, and testing of navigational lights and special signaling lights.

The measurements described in this report were conducted during the period 1 July 1964 to 15 February 1965. This is an interim report. Work on the problem is continuing.

APPROVED AND RELEASED 25 JANUARY 1966

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Subj: NAVMINDEFLAB Unclassified Report i-95 of April 1966; information concerning

1. This report describes threshold visibility tests and results on a simulated submarine light array.

2. The report is forwarded to document the technical information contained herein and to distribute it to interested activities.

R. T. Miller
R. T. MILLER

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INTRODUCTION

The U. S. Navy Mine Defense Laboratory has undertaken the problem of development, improvement, and testing of navigational lights and special signaling lights. Several near collisions between nuclear submarines and merchant vessels indicate a critical need for improvement in the submarine light array. Prior to the development of new lights it was considered necessary to determine how far the present lights are visible with the unaided eye, at sea, under known normal nighttime operating conditions, with shipboard military observers. In order to determine the threshold visibility range of the present lights, a calibrated light range was established in the Gulf of Mexico; this range permits monitoring of the atmospheric transmission rate during all tests. A simulated nuclear submarine (SSN) running light array was constructed and mounted on the Laboratory's offshore platform, designated Stage I, in the vicinity of the calibrated light range. Tests were conducted under various atmospheric conditions and with various observers whose vision had been tested and accepted as normal.

NAVIGATIONAL LIGHTS AND EQUIPMENT

LAMPS

Two types of lamps were used in the submarine light array tests, the T-12 50/50 watt and TS-121 100/100 watt (the designation 50/50 watt means a 50-watt rating for each filament). Both types are dual filament lamps. All tests described herein were conducted with only one filament operating with a potential of 115 volts a-c applied.

LIGHT FIXTURES

Three navigation light fixtures were used in the submarine light tests. These were type MS17789 masthead light with a clear lens type MS16867-1, type MS17788-1 port sidelight with red lens type MS16867-2, and type MS17788-2 starboard light with green lens type MS16867-3.

SUBMARINE ARRAY

The light fixtures and lamps discussed above were assembled in an array approximating that of a SSN, as shown in Figure 1. Tests were conducted successively with the 50/50-watt lamps and the 100/100-watt lamps. During all tests all the lamps in the array were of the same power rating and all were operating at the same time. That is, when a 50/50-watt lamp was used in the masthead lamp, the two sidelights were each operating with 50/50-watt lamps also.

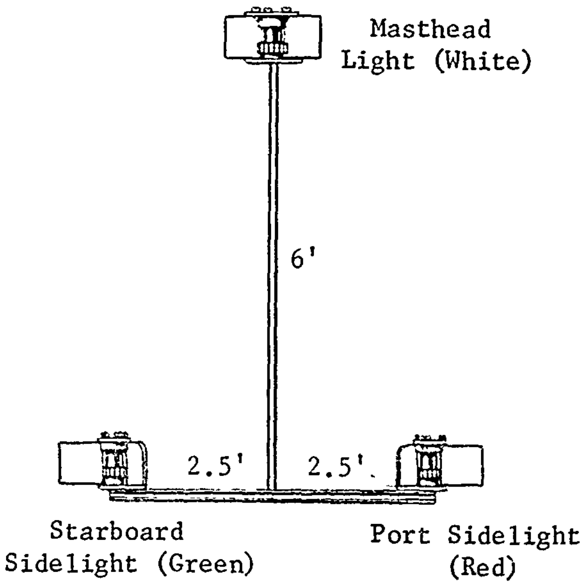

FIGURE 1. SIMULATED SUBMARINE ARRAY

VISIBILITY TESTS

TEST SETUP

The U. S. Navy Mine Defense Laboratory (NAVMINDEFLAB) light range (Appendix A) was established to record the atmospheric transmission rate continuously during all threshold visibility measurements at sea in order that all ranging data collected may be corrected to the normalized atmospheric transmission rate of 70 percent per nautical mile (Appendix B).

The submarine light array was mounted 12 feet above mean water level on the northwest side of offshore platform Stage I. Stage I is approximately 12 miles off shore from Panama City, Florida, and is in the

vicinity of the NAVMINDEFLAB calibrated light range. Figure 2 shows the northwest side of Stage I with the submarine array drawn in. The submarine array was connected to the 115 volt a-c power supply on Stage I.

OBSERVERS

The observers who participated in this study were selected from military personnel who stand duty watch as lookouts on board USS VENTURE (MSO 496). Each observer was given an industrial type eye examination utilizing the Bausch and Lomb Ortho-Rater. Only observers who had 20-20 vision and normal color perception were selected to participate in visibility tests. These observers were well qualified for this duty through training and experience. The work was performed at times under adverse conditions for the observers on the open bridge of the ship. At various times the men were exposed to high winds, rainstorms, cold weather, and rough seas. At least three observers were on duty during all measurements. Generally, the observers stood 4-hour watches. All data reported herein was recorded when the atmospheric transmission rate was 65 percent per mile or above, and all observations were made with the unaided eye.

TEST PROCEDURE

Threshold visibility measurements were conducted at night in the vicinity of the NAVMINDEFLAB calibrated light range. The observers were stationed on the bridge of the USS VENTURE and made observations while steaming away from Stage I (westward) and while returning toward Stage I. The observers were given range "marks" every quarter mile and instructed to record all lights they could see with the unaided eye at each mark. Stage I was blacked out except the lights under test, and all lights on the USS VENTURE that would have been visible to the observers were secured. Tests were suspended when other ships passed through the test area and until they were well clear.

TEST RESULTS

The results of the threshold visibility measurements are summarized in Table 1. The results given are average figures for military observers with unaided eyes dead ahead of the full simulated submarine array.

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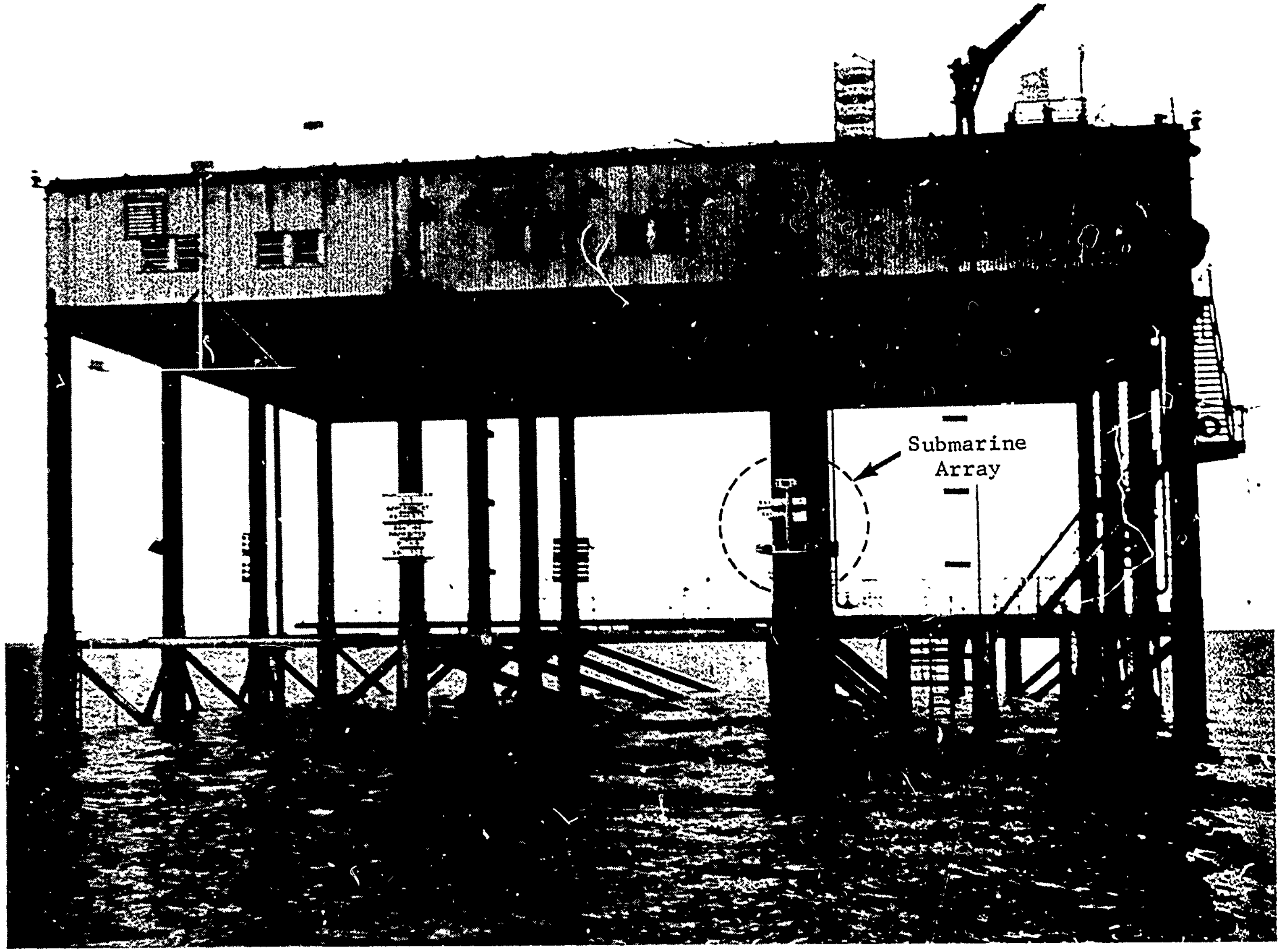

FIGURE 2. SUBMARINE ARRAY LOCATION ON STAGE I

TABLE 1

SUBMARINE ARRAY SUMMARY

Lamp	Lens*	Number of Observations**	Observed Threshold Range (Miles***)	Computed 70 Percent/ Mile Threshold (Miles)	Standard Deviation (Miles)
50/50	Clear	21	9.3 (Horizon)		
50/50	Red	58	2.3	2.3	.51
50/50	Green	57	2.1	2.1	.51
100/100	Clear	10	9.3 (Horizon)		
100/100	Red	56	2.5	2.1	.51
100/100	Green	62	2.5	2.1	.61

*Plain Lenses Type MS16867

**An observation is defined as a single determination by one observer of the range at which the light is barely visible.

***Ranges given in nautical miles.

The threshold visibility range for the normalized atmospheric transmission rate of 70 percent per nautical mile was computed by the method outlined in Appendix B for the side lights. The masthead light threshold range was limited by the horizon and is recorded as observed. Standard deviation was computed by methods outlined in Reference 5.

REMARKS

Preliminary analysis of the presented data unexpectedly shows that increased lamp intensity did not increase the threshold visibility range, and the threshold visibility range of the green starboard side light was no greater than that of the red port sidelight. If, however,

the minimum angle of resolution of the eye is considered, some light may be shed on these results. The minimum angle of resolution for the human eye has been given variously as from 1 minute to 1.75 minutes by References 1 and 2. If at the maximum range of the submarine array of 2.3 miles, 1 minute is accepted as the minimum angle of resolution, the minimum field would be 4 feet. At the same range the minimum field for 1.5 minutes would be 6.1 feet. It is readily apparent that the light spacing of 6.5 feet at this range is closely approaching the minimum angle of resolution for the human eye. Also, the Committee on Colorimetry of the Optical Society of America in "The Science of Color," p. 51, offers the following statement: "The color sensation arising from a given quality of light is influenced by the color of light coming from the immediately surrounding area, particularly if there is a marked difference in the qualities or intensities of the light from these two sources." Reference 4 stated that a bright object in the field of view might impair visual performance. It is therefore obvious that, as in these tests, when viewing closely spaced lights of various colors from long ranges, many factors are involved other than the threshold visibility range of any one light.

The observers complained repeatedly that the bright white masthead light interfered with their seeing the sidelights. All measurements discussed herein were conducted on the submarine array as a whole, rather than on any particular light in the array. Tests were conducted in this manner to approximate as nearly as possible actual operating conditions. No runs were conducted on the sidelights to determine their threshold visibility when operating alone. However, tests were conducted on these same fixtures in a simulated destroyer (DD) array with its wider spacing and were visible approximately 4 miles. A report on these destroyer array tests is being drafted and will be submitted at a later date.

The white masthead light with a 50-watt lamp installed was clearly visible to the horizon when the atmospheric transmission rate was 70 percent/mile. There may be some merit in the argument that it need not be of any higher intensity, especially if higher intensity offers more interference for the observer and results in a reduced threshold visibility range on the complete array. During periods of reduced visibility, when the threshold visibility range of the white light is limited by atmospheric and inverse square law attenuation instead of the horizon, increased intensity would offer increased threshold visibility.

CONCLUSIONS

The results of threshold visibility tests at sea indicate that both 50/50 watt lamps and 100/100 watt lamps in the white masthead light of

the submarine array are visible to the horizon (9.3 miles). It is also indicated that the greatest range the submarine array can be recognized as such is 2.3 miles.

Since the spacing of the running lights on each submarine is fixed by the design of the submarine itself, and tests indicate that these lights are visible to near the minimum angle of resolution for the unaided human eye, the only avenue left open for large increases in the range of identification is by additional lights. The outfitting of submarines with a unique light such as a rotating beacon or a high intensity flashing light offers one possible solution.

FUTURE WORK

Much work remains to be done toward improving the range of the submarine light array. Some of the ideas that seem to offer promise and merit further study are: (1) a shift in chromaticity of the white light toward the blue region to give a softer white with less glare, (2) a reduction in the intensity of the white light, (3) an increase in the intensity of the light source in the colored sidelights so the radiated energy is equal to that of the white light, and (4) a shift in chromaticity of the colored sidelights. The increase in intensity of the sidelights might also be satisfactorily accomplished through the use of half-silvered lamps or half-silvered lenses to reflect and utilize the light presently lost on the back side. These and other ideas are being considered and those which show promise will be tested at sea in the same manner as tests described herein.

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APPENDIX A

LIGHT TRANSMISSION RANGE

INTRODUCTION

A calibrated light transmission range has been established by the U. S. Navy Mine Defense Laboratory (NAVMINDEFLAB) approximately 12 miles offshore from Panama City, Florida, in the vicinity of Stage I. This range was established to permit continuous monitoring of the atmospheric transmission rate during threshold visibility measurements of various navigational lights.

RANGE DESCRIPTION

A 36-inch searchlight is mounted on Stage I as shown in Figure A1 and directed toward Stage II, 9.25 nautical miles in toward shore, as shown in Figure A2. The carbon arc lamp has been removed and replaced by a 1000-watt projection type lamp which is located at the principal focus of the parabolic mirror. The lamp is surrounded by a cylinder which has two openings. The open-sided cylinder is attached to and rotated by an 1800-rpm motor. When the lamp and motor are operated, a 60-cycle chopped light beam is produced.

A light receiver is mounted on top of Stage II as shown in Figure A3. A lens, parabolic mirror, photo tube, and preamplifier are located in the receiver barrel. Also, a power supply, 60-cycle amplifier, and recorder are located in the instrument room on Stage II as shown in Figure A4. Figure A5 is a block diagram of the light transmitter and receiver (transmissometer).

The 60-cycle chopped searchlight beam from Stage I falls on the parabolic mirror in the receiver barrel on Stage II where it is focused on the photocell mounted at the principal focus of the receiver mirror. The signal received by the photocell is fed through the preamplifier stage in the receiver barrel to a cable leading to the 60-cycle amplifier located on deck below. In the 60-cycle amplifier the signal is simply amplified, rectified, and fed to a chart recorder.

CALIBRATION

Prior to calibration, the searchlight on Stage I and the receiver barrel on Stage II must have been carefully aligned with each other and

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FIGURE A1. LIGHT TRANSMITTER

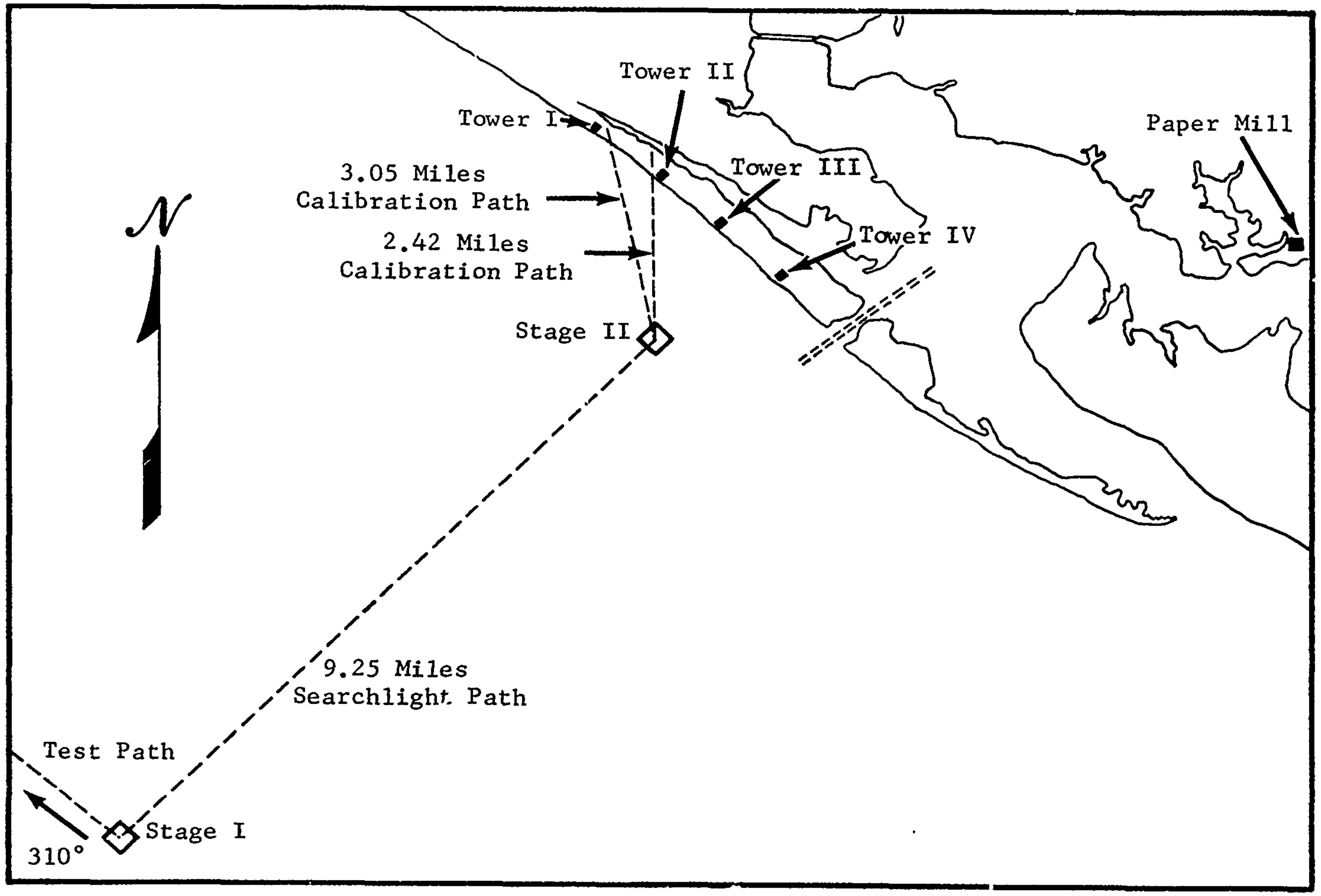

FIGURE A2. MDL LIGHT RANGE

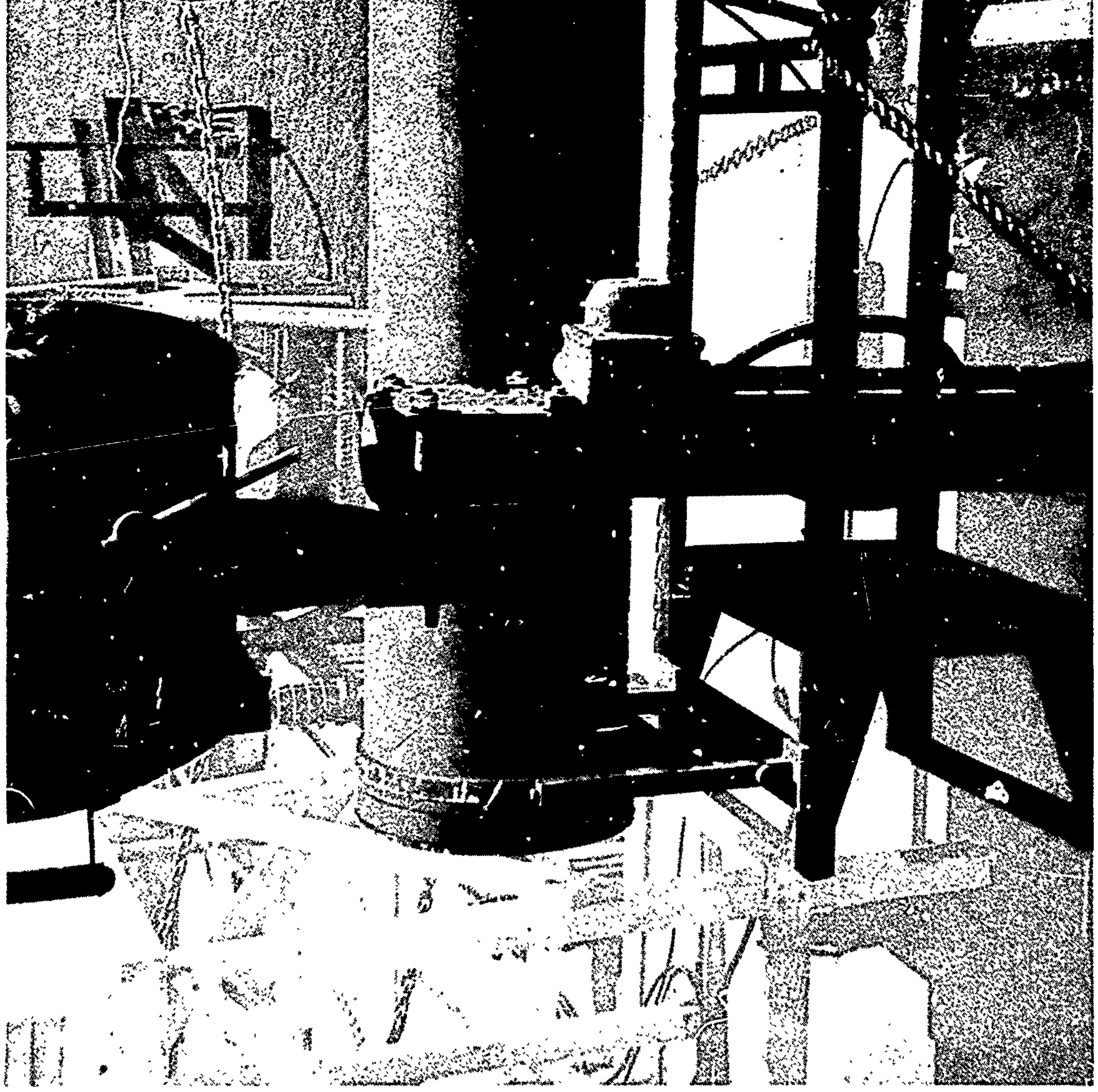

FIGURE A3. TRANSMISSOMETER RECEIVER

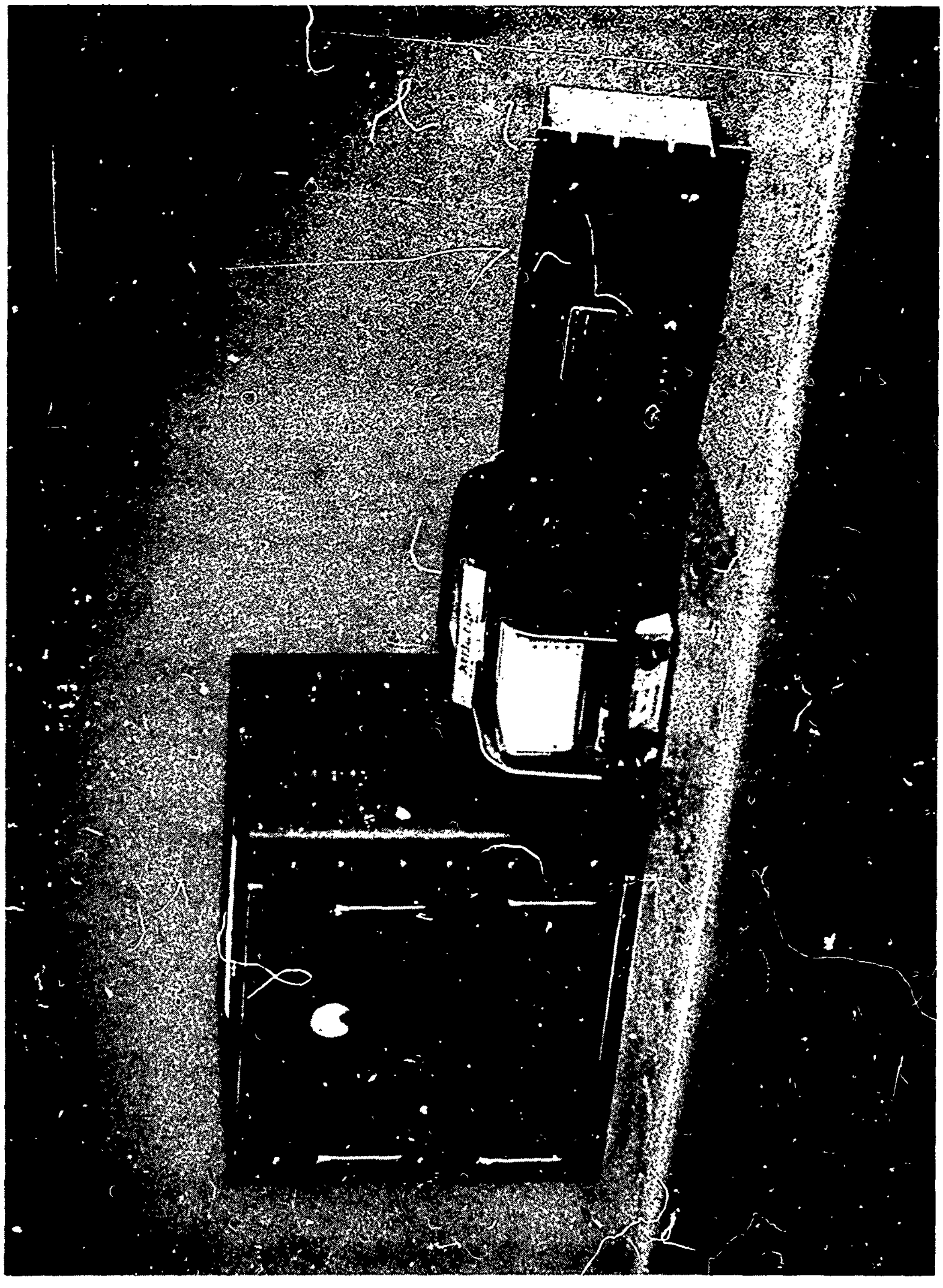

FIGURE A4. RECEIVER INSTRUMENTATION

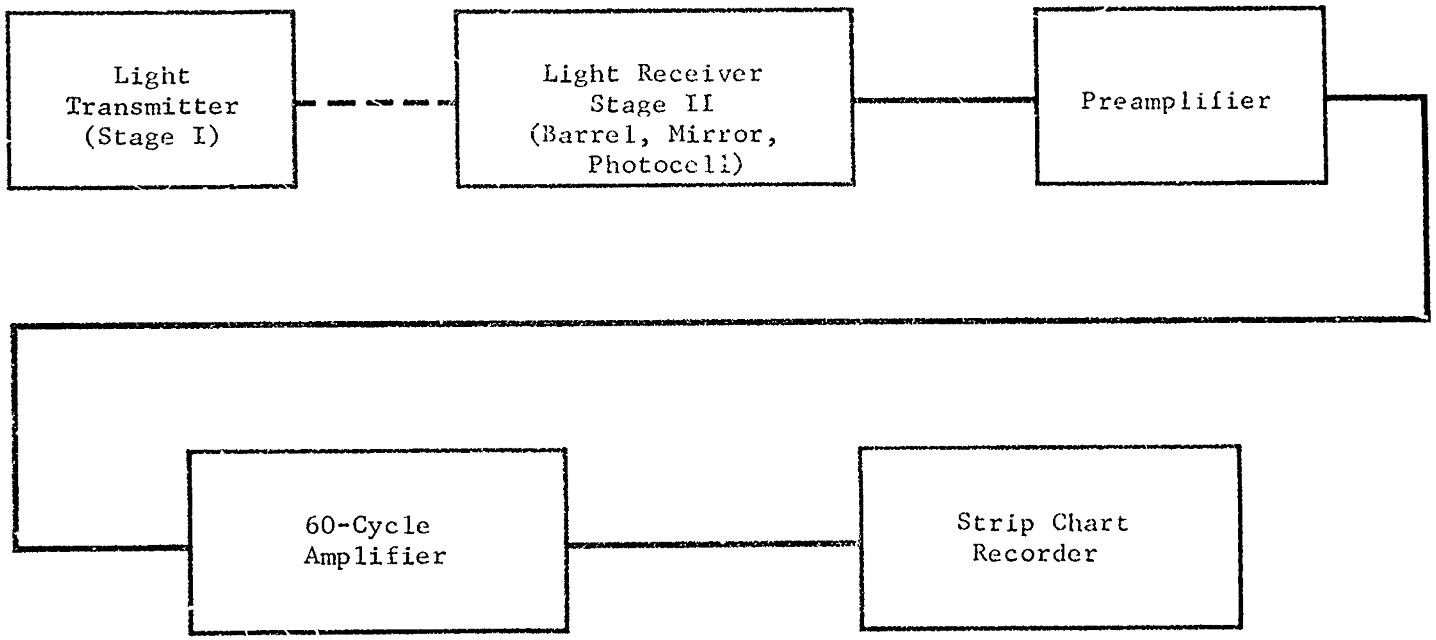

FIGURE A5. TRANSMISSOMETER BLOCK DIAGRAM

locked securely in place. The searchlight is anchored with three half-inch cables and turnbuckles. The receiver barrel is also bolted to the deck. The searchlight and receiver are switched on and allowed to warm up for at least 30 minutes. Through the use of an optical pyrometer with telescopic lens attached, color temperature readings are made over the two calibration paths from Stage II to SOTS Tower 1, 3.05 miles away, and from Stage II to Tower 2, 2.42 miles away, as shown in Figure A2. Color temperature readings are taken on the pine forests (equivalent to a black body) adjacent to Tower 1 and Tower 2 and on the horizon sky immediately above each. Through the use of Table A1, these color temperature readings are converted to brilliance figures. The two brilliance figures for each calibration path are inserted in the Koschmieder relationship:

$$T = \frac{B_H - B_B}{B_H} \tag{A1}$$

where T = the atmospheric transmission rate over the path measured

B_H = horizon brilliance

B_B = black body brilliance of the forest.

This calculation gives the atmospheric transmission rate over the observed paths at the time observed. These atmospheric transmission rates for 2.42 miles and 3.05 miles are then converted to 1-mile rates by successive insertion in the relationship

$$T_2 = (T_1)^{d_2/d_1} \tag{A2}$$

where T_1 = the atmospheric transmission rate over the measured path

T_2 = the 1-mile atmospheric transmission rate

d_2 = 1 mile

d_1 = measured path (2.42 or 3.05 miles).

These calculations produce two sets of figures for the 1-mile atmospheric transmission rate. These two figures are averaged and the average is used as the 1-mile atmospheric transmission rate.

After the average 1-mile atmospheric transmission rate has been computed, this figure is again inserted in Equation (A2) to determine the 9.25-mile atmospheric transmission rate. In this calculation, T_2 is the 9.25-mile atmospheric transmission rate, T_1 is the 1-mile atmospheric transmission rate, d_1 is 1 mile, and d_2 is 9.25 miles. Proper adjustment of the gain control on the amplifier will calibrate the recorder,

(Text Continued on Page 19)

TABLE A1

COLOR TEMPERATURE TO BRILLIANCE CONVERSION TABLE
(λ = 5350 A)

T°C	Jλ	T°C	Jλ	T°C	Jλ	T°C	Jλ
850	3.08 - 6	950	2.42 - 5	1050	1.27 - 4	1150	5.30 - 4
855	3.49	955	2.65	1055	1.38	1155	5.64
860	3.92	960	2.90	1060	1.50	1160	6.02
865	4.37	965	3.18	1065	1.62	1165	6.42
870	4.86	970	3.48	1070	1.75	1170	6.85
875	5.40	975	3.80	1075	1.89	1175	7.30
880	6.01	980	4.14	1080	2.04	1180	7.49
885	6.68	985	4.50	1085	2.19	1185	8.30
890	7.42	990	4.90	1090	2.35	1190	8.84
895	8.20	995	5.31	1095	2.52	1195	9.40
900	9.06	1000	5.77	1100	2.71	1200	1.00 - 3
905	1.01 - 5	1005	6.27	1105	2.91	1205	1.07
910	1.11	1010	6.81	1110	3.12	1210	1.14
915	1.22	1015	7.39	1115	3.34	1215	1.21
920	1.35	1020	8.00	1120	3.57	1220	1.28
925	1.49	1025	8.64	1125	3.82	1225	1.35
930	1.65	1030	9.30	1130	4.08	1230	1.43
935	1.82	1035	1.00 - 4	1135	4.36	1235	1.52
940	2.00	1040	1.08	1140	4.65	1240	1.62
945	2.20	1045	1.17	1145	4.97	1245	1.72
950	2.42	1050	1.27	1150	5.30	1250	1.82

giving a readout equal to the 9.25-mile computed atmospheric transmission rate based on measurements over the two calibration paths.

During periods when threshold visibility measurements are underway the receiver calibration is rechecked frequently. Generally the calibration is checked at the start of measurements on the first of the week and after tests are secured at the end of the week's tests. Also, during tests the calibration is rechecked at least every two days. These frequent checks, though laborious, have proved to be worthwhile in that minor deficiencies can be detected quickly and corrected before tests are resumed. This prevents the collection of data when the atmospheric transmission rate is either unknown or in doubt.

A typical calibration check was conducted on the morning of 8 December 1964 which is offered as an example. Color temperature measurements were made with the optical pyrometer on the horizon sky above and pine forests adjacent to Towers 1 and 2. At Tower 1 the color temperature readings were 915 C and 945 C on forest and horizon sky, respectively. At tower 2 the readings were 900 C and 945 C on the forest and horizon sky, respectively. Through the use of Table A1, these convert to brilliance figures as follows:

Tower 1,	$T_B = 915$ C	$B_B = 1.22 \times 10^{-5}$
	$T_H = 945$ C	$B_H = 2.20 \times 10^{-5}$
Tower 2,	$T_B = 900$ C	$B_B = 9.06 \times 10^{-6}$
	$T_H = 945$ C	$B_H = 2.20 \times 10^{-5}$

The 3.05-mile atmospheric transmission rate is computed by inserting these values in the Koschmieder relationship (Equation (A1)).

$$T_{(3.05 \text{ miles})} = \frac{2.20 \times 10^{-5} - 1.22 \times 10^{-5}}{2.20 \times 10^{-5}} = .45 \text{ or } 45 \text{ percent}$$

The 3.05-mile atmospheric transmission rate is then converted to a 1-mile rate by inserting the known values in Equation (A2).

$$T_{(1 \text{ mile})} = (.45)^{1/3.05} = .77 \text{ or } 77 \text{ percent}$$

Similarly, the 2.42-mile atmospheric transmission rate is computed by inserting the known values again in Equation (A2).

$$T_{(2.42 \text{ miles})} = \frac{2.20 \times 10^{-5} - 9.06 \times 10^{-6}}{2.20 \times 10^{-5}} = .50 \text{ or } 50 \text{ percent}$$

Again the 1-mile atmospheric transmission rate is computed by inserting the known value in Equation (2).

$$T_{(1\ \text{mile})} = (.50)^{1/2.42} = .75 \text{ or } 75 \text{ percent}$$

Therefore, the average 1-mile atmospheric transmission rate as measured and computed for these two paths is .76 or 76 percent per mile.

The 1-mile atmospheric transmission rate must now be converted to a 9.25-mile rate in order to calibrate the recorder. The 9.25-mile rate is then computed by again inserting known values in Equation (2), which yields

$$T_{(1\ \text{mile})} = (.76)^{9.25/1} = .078 \text{ or } 7.8 \text{ percent.}$$

Figure A6 is a simplified reproduction of the recorder strip chart for this calibration on 8 December 1964. Full scale on the chart represents a 9.25-mile atmospheric transmission rate over the searchlight transmission path of .20 or 20 percent. The point marked A was at the time of this calibration on the chart. The mean value for the swing of the pen at this point agrees very well with the measured and computed value of .078.

By similar methods the atmospheric transmission rate was measured and computed 1¼ hours later for 9.25 miles and was determined to be .10 or 10 percent, which can be read at point B on chart, as shown in Figure A6. NOTE: The wide area painted by the recorder pen on the chart at this time represents a noise level that is not entirely typical of the system. Generally, the noise level was less than that indicated by the pen swing at this point.

PROBLEMS

Many problems are to be expected in field measurements and this is especially true in measurements such as these conducted at sea. One of the more basic problems with the light range as described herein is that the three light paths involved in calibration and measurements are three entirely different paths as may be been in Figure A2. The calibration paths run from Stage II to Tower 1 and Tower 2 on shore. The searchlight transmission path runs from Stage I to Stage II. Then the test path runs west of Stage I. One must assume that the atmospheric transmission rate over these four paths is the same, which, of course, is not always a valid assumption.

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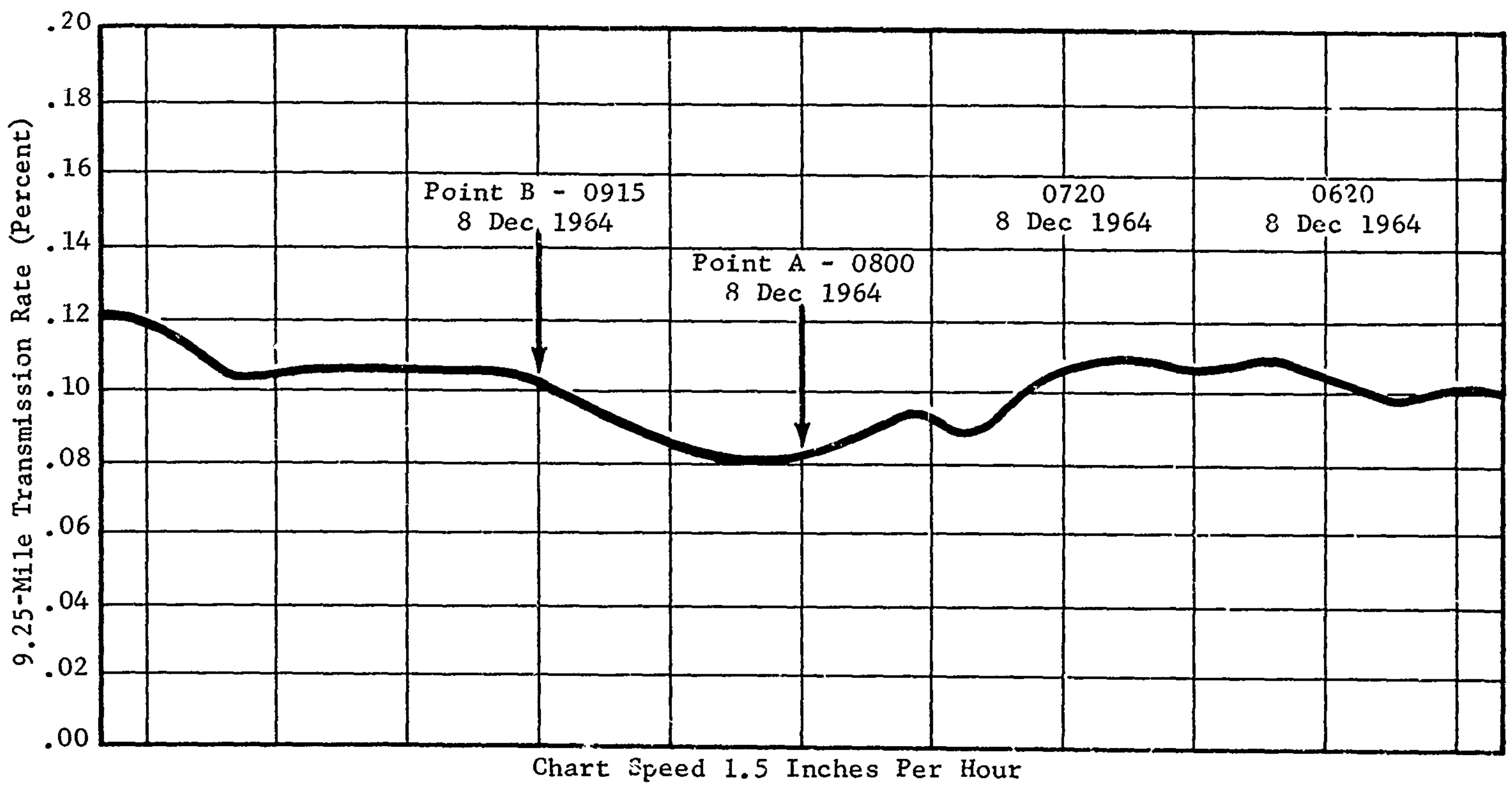

FIGURE A6. RECORDER CHART

A large paper mill is located about 8 miles east of Tower 2, as shown in Figure A2. Frequently, when the wind is out of the east or northeast, the exhaust fumes, or smog, from this mill have one or more of the following effects: (1) obscure the forest at Tower 1 or Tower 2 from the observer on Stage II, (2) drift across the searchlight transmission path between Stage I and Stage II, or (3) drift into the test area west of Stage I. Also, during periods of scattered thundershowers, any one of these four paths may be blocked while visibility remains unchanged on the others.

Calibration was attempted only at times when it appeared that the atmospheric conditions were roughly the same over the path from Stage I to Stage II, and from Stage II to Tower 1 and Tower 2 on shore. Also, tests were conducted only when it appeared that the atmospheric conditions were roughly the same over the searchlight path between Stage I and Stage II and over the test path west of Stage I.

Another recurring problem is that the lens of the receiver becomes translucent due to a coating of condensation being formed sometimes on the inside and sometimes on the outside of the lens. When this occurs even if the atmospheric transmission rate is at a high level, the recorder indications will drop to zero. Frequent checks must be made to determine that the lens is clear. Also, the receiver parabolic mirror sometimes becomes coated with water droplets producing the same results as the lens coating problem. When either of these conditions occur tests must be suspended until the lens or mirror is cleaned and the system recalibrated.

Calibration must be accomplished during the morning on a clear day due to the fact that the receiver barrel faces southwest and in the afternoon the sun reflects off the water into the receiver, causing a high noise level. Calibration cannot be accomplished when the sky is overcast due to the horizon sky being obscured over Tower 1 and Tower 2.

APPENDIX B

THRESHOLD RANGE CONVERSION

In order to convert threshold visibility data to the normalized 70 percent per mile transmission rate, Allard's Law is utilized. Allard's Law states that the illuminance produced by a distant source is directly proportional to the transmission rate per unit distance of the medium through which light is transmitted and the source intensity and inversely proportional to the square of the distance through the medium. In algebraic notation Allard's Law is written

$$E = \frac{IT^d}{d^2} \tag{B1}$$

where:

E = Illuminance

I = Source Intensity

T = Transmittance per Unit Distance

d = Distance

Of course, since $T = e^{-\alpha}$, where α is the attenuation coefficient per unit distance, it follows also that

$$E = \frac{Ie^{-\alpha d}}{d^2} \tag{B2}$$

From (1) above it follows that

$$\frac{T_1^{d1}}{2} = \frac{T_2^{d2}}{d_2^2} \tag{B3}$$

Since T_1, the measured atmospheric transmission rate, T_2, the standard 70 percent per mile atmospheric transmission rate, are known along with d_1, the measured threshold visibility range, d_2, the threshold visibility range for the normalized atmospheric transmission rate of 70 percent per mile may be computed.

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References: 7 refs.
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NO 3

1. Navigational lights - Visibility
2. Submarine navigational lights - Visibility
3. Light - Atmospheric transmission
4. Light - Measurement - Transmission - Range

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NO 4

1. Navigational lights - Visibility
2. Submarine navigational lights - Visibility
3. Light - Atmospheric transmission
4. Light - Measurement - Transmission - Range

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NO 1

1. Navigational lights - Visibility
2. Submarine navigational lights - Visibility
3. Light - Atmospheric transmission
4. Light - Measurement - Transmission - Range

I. Title
II. Larrimore, Herbert
III. SF 013 12 08
IV. Task 4601

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NO 2

1. Navigational lights - Visibility
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NO 3

1. Navigational lights - Visibility
2. Submarine navigational lights - Visibility
3. Light - Atmospheric transmission
4. Light - Measurement - Transmission - Range

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NO. 4

1. Navigational lights - Visibility
2. Submarine navigational lights - Visibility
3. Light - Atmospheric transmission
4. Light - Measurement - Transmission - Range

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NO 2

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2. Submarine navigational lights - Visibility
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13 ABSTRACT

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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